DISPOSAL OF CONVENTIONAL WEAPONS BY CONFINED DETONATION

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THESIS

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BY CONFINED DETONATION

by

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Disposal of Conventional Weapons

by Confined Detonation

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ABSTRACT

A miniature detonation chamber has been designed and manufactured to allow loading, detonation, reloading, and gas sampling without appreciable loss of products or pressure. The actual products of detonation are compared with the theoretical products. From this comparison, a study is made of the effects on the environment from sequential, confined detonation of conventional explosives in an Atomic Energy Commission test site.

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I. INTRODUCTION

An important problem today in the Military is the disposal of obsolete and hazardous munitions. With the increased attention being given to environmental protection, it is no longer practical to dispose of our discarded munitions in the sea with the hope they will be permanently lost in the vastness of the ocean floor. As the potential of harvest from the sea increases, it is necessary to consider the long range ramifications resulting from adding tens of thousands of tons of CHON conventional explosives to the ocean, as well as the hazard presented to ocean commerce. Similarly, open burning of explosives is not a satisfactory answer. The combustion products of burning are chiefly oxides of nitrogen, carbon, and hydrocarbons, which are already an environmental pollution problem from existing industries. Therefore, a practical and ideal solution to the disposal must not be subject to criticism on environmental grounds.

II. PROPOSAL

To safely and practically dispose of conventional explosives, it is proposed that they be detonated in confined underground chambers. Recent blasts by the Atomic Energy Commission have shown the feasibility of this solution. The concentration and power of conventional explosives disposal would in no way approach the magnitude of the underground thermonuclear detonations that have been successfully completed. Thus, with the knowledge gained from the AEC underground tests, it would be safe to dispose of several thousand tons of conventional weapons without undue blast damage or venting noxious gases to the atmosphere.

To test the environmental effects of the proposed method, an explosion chamber was constructed of stainless steel. This chamber permitted detonation of up to three grams of explosive, containing the gases and pressure, and reloading the chamber. An unlimited number of successive detonations may be made in this manner, and the build-up of gases can be studied.

III. THEORY

To properly investigate the results of sequential detonation within a closed container, the theoretical products of detonation must be known with respect to identification and quantity. Several methods have been used for this purpose on an historical basis, but these methods were too simple with respect to the products formed. They allowed no latitude for interactions and equilibrium considerations among the gaseous products. A specific example is the water-gas reaction;

$$H_2O + CO = H_2 + CO_2.$$

If this reaction occurred, the products of the detonation would shift in proportion to a greater or lesser extent, depending upon the rate constant.

The utilization of computers, coupled with an appropriate equation of state for the gas, considers all parameters for the solution to the theoretical products of detonation. Cook, [1958], details the procedure and theory behind computer solutions, and lists a table of values for several explosives at various packing densities.

Trinitrotolulene (TNT), is of major interest since it is used in so many explosives either pure or in a mixed form. Hand tamping of TNT results in a packing density of 0.90 to 1.00. Using 0.95 g/cc as an average density, Cook gives the following values as the theoretical products of detonation.

PRODUCT	MOLES PRODUCED (per kg)
CO	12.1
CO_2	5.2
H_2	0.9
H_2O	2.4
N_2	5.2
CH_4	1.0
NH_3	0.5
CH_3OH	1.6
HCN	2.8
C_2H_2	0.3
C	7.4

For a density of 0.95 g/cc, the temperature of the detonation is calculated to be 3580° K. Fugacity constants for this temperature are in table ii.2, Appendix II, of Cook, [1958]. The fugacity constants are used to solve for the equilibrium constants for all possible reactions of the explosive and its gases in the presence of free carbon. The equilibrium constants, after being used in an appropriate equation of state, give the number of moles of each product of the detonation. This data is not corrected for possible equilibrium shifts occurring during the rapid cooling to ambient temperature.

The above values will be used as the theoretical expected values for the products of detonation. The calculated values, determined by analysis of the gas samples, will be compared.

Since there is no pressure gage on the detonation chamber, the theoretical pressure must be calculated to enable calculation of the mass of gases produced by the explosion. A graph showing the percentage of a gas present is meaningless by itself; an unexpected increase or decrease in the rate of production will provide useful data. The pressure calculations, as were the product and equilibrium considerations, are made for trinitrotolulene.

The data for Cook [1958], using equilibrium considerations, gives a total of 784.0 liters of gas resulting from the detonation of one kilogram of TNT. If contained in the detonation chamber volumn of 19.57 liters (APPENDIX A) this would result in a pressure of 40.07 atmospheres, plus one atmosphere for the ambient conditions, equals 41.07 atmospheres.

The Engineering Design Handbook, [1971], gives the value of 730 cc of gases per gram of TNT. If one kilogram of TNT was detonated in an ambient atmosphere in the detonation chamber, this would produce a pressure of 38.31 atmospheres.

In an actual situation, there is a possibility of a certain amount of combustion or deflagration as well as detonation. Sewell and Sinclair, [1972], developed the concept of V_{cd}; the change in gaseous volume occurring when both detonation and deflagration occur. Since this incorporates the oxygen contained in a confined space, the appliciability to the described detonation chamber is enhanced.

Calculation of the volume of combustion and detonation gases yield a pressure of 51.43 atmospheres for one kilogram of TNT in the chamber (APPENDIX B). This method of calculation of the pressure will be used, since pure detonation cannot be assumed.

IV. EXPERIMENTAL PROCEDURE

A. DESIGN AND OPERATION OF THE DETONATION CHAMBER

The detonation chamber was designed to detonate the explosive, contain the gases, permit tapping for analysis, and be reloaded. The chamber was made of stainless steel periscope housing (FIG. 1). A sample tube passed through an airlock permitting loading when withdrawn, and detonation when inserted. (FIG 4). The volume of gases lost each shot was limited to the small volume of the explosive compartment in the insertion tube. A circular flange on the bottom of the insertion tube prevented total withdrawl from the chamber and served as a blast shield.

The firing circuit was critical, since a non-firing resulted in the abortion of an entire series. The sample, once inserted, could not be withdrawn and inspected since the wires supporting the charge would have been severed when passing through the airlock (FIG. 3). Another important consideration was the position of the blasting cap and explosive at the time of detonation. If the explosive remained in the vicinity of the insertion tube, severe metal damage would result upon detonation. Although time consuming, the method presented below yielded no failures.

A squib, or detonator, was selected which would screw into the top of the insertion tube. Through a small hole drilled through the top of the detonator, two insulated copper wires were passed, and the cavity of the detonator

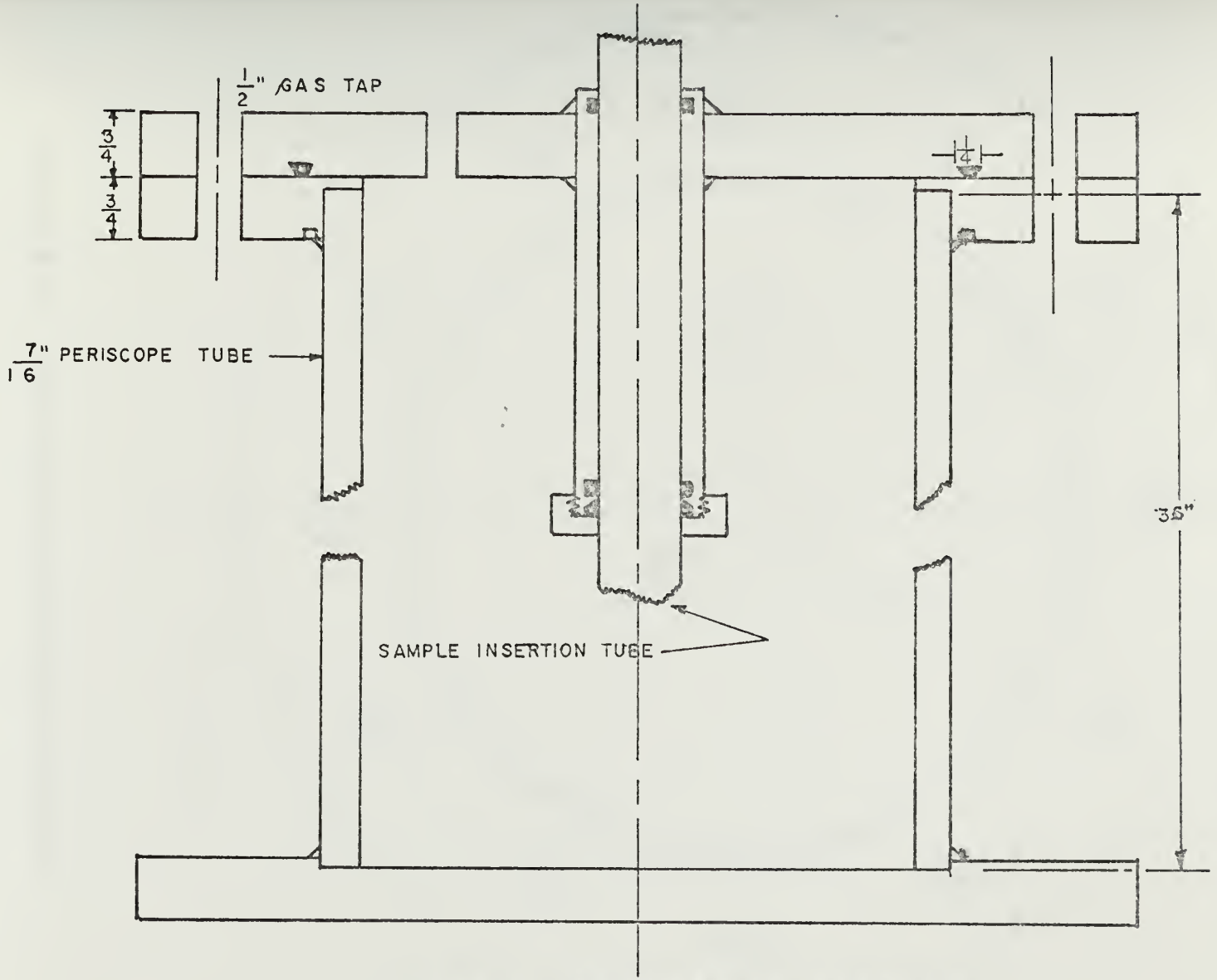


FIGURE 1: DETONATION CHAMBER

FIGURE 2: DETONATION CHAMBER COVER

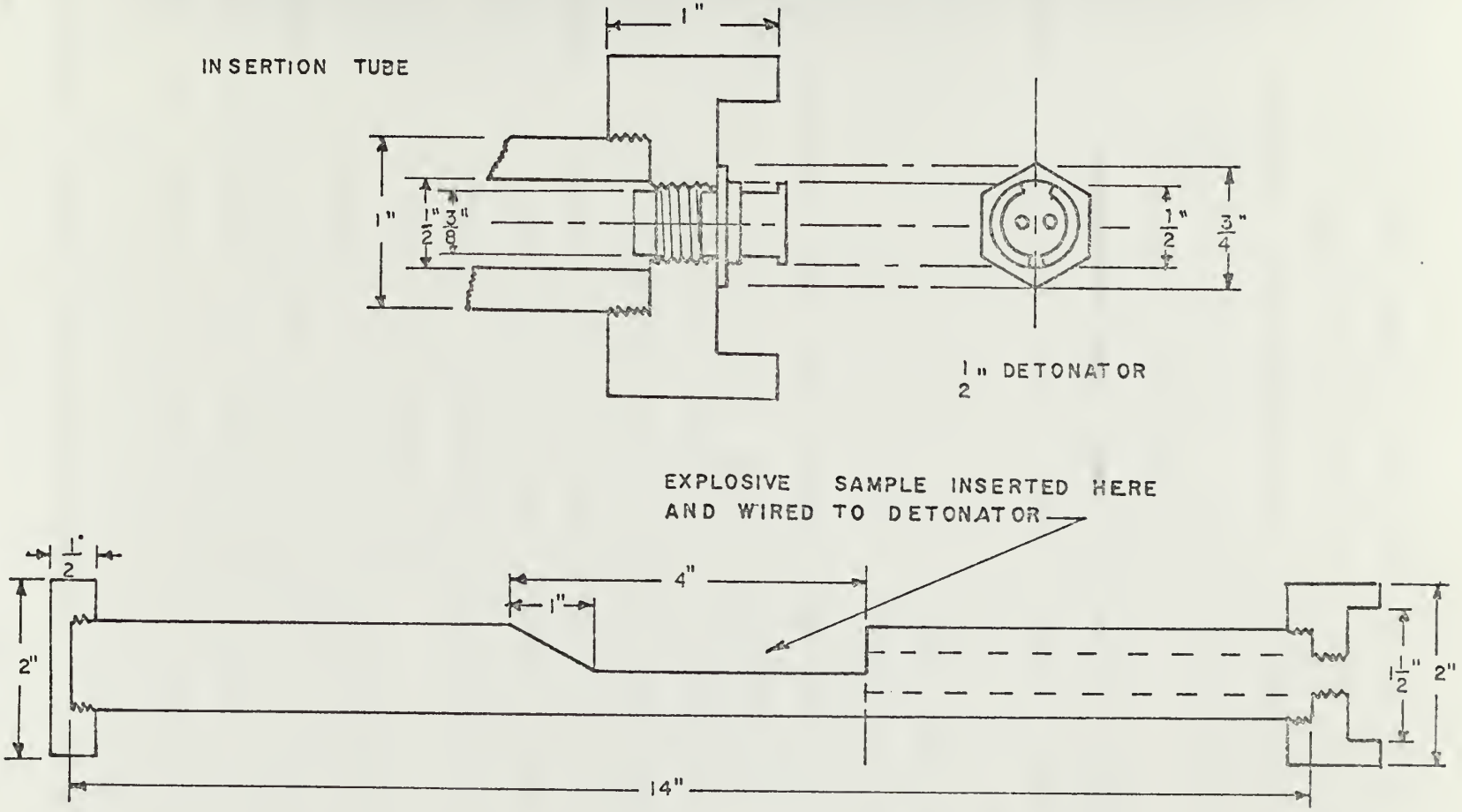


FIGURE 3: SAMPLE INSERTION TUBE

was filled with steel epoxy. The wires on top of the detonator were stripped for attachment to an A. C. line source, and those on the bottom were passed through the hole in the insertion tube (FIG. 5). Solderless connectors were attached to the wires in the sample area.

To allow the explosive to drop away from the sample compartment, the rigid wires of the blasting cap had to be removed and be replaced with a more flexible wire. However, the wire had to be strong enough not to break from the weight of the sample, yet sever when passed through the airlock. After considerable experimentation, it was found that #31 enameled copper wire performed in the required manner. A thirty inch section of the enameled wire was mechanically attached to the stripped inch long leads of the blasting cap. Mechanical attachment was made vice soldering due to the danger of heat being conducted along the short lead of the cap. After attachment, the enameled wire was left in a loop to electrically short the blasting cap.

Loading procedure was in line with established safety procedures for explosives. After pulling the insertion tube to the load position, the enameled wire was cut in the center of the loop, and the A. C. leads atop the detonator were shortened. The ends of the enameled wire were sanded one and one half inches to remove the insulation, and wound around the solderless connectors in the sample area. The paper cylinder containing the explosive was then attached to

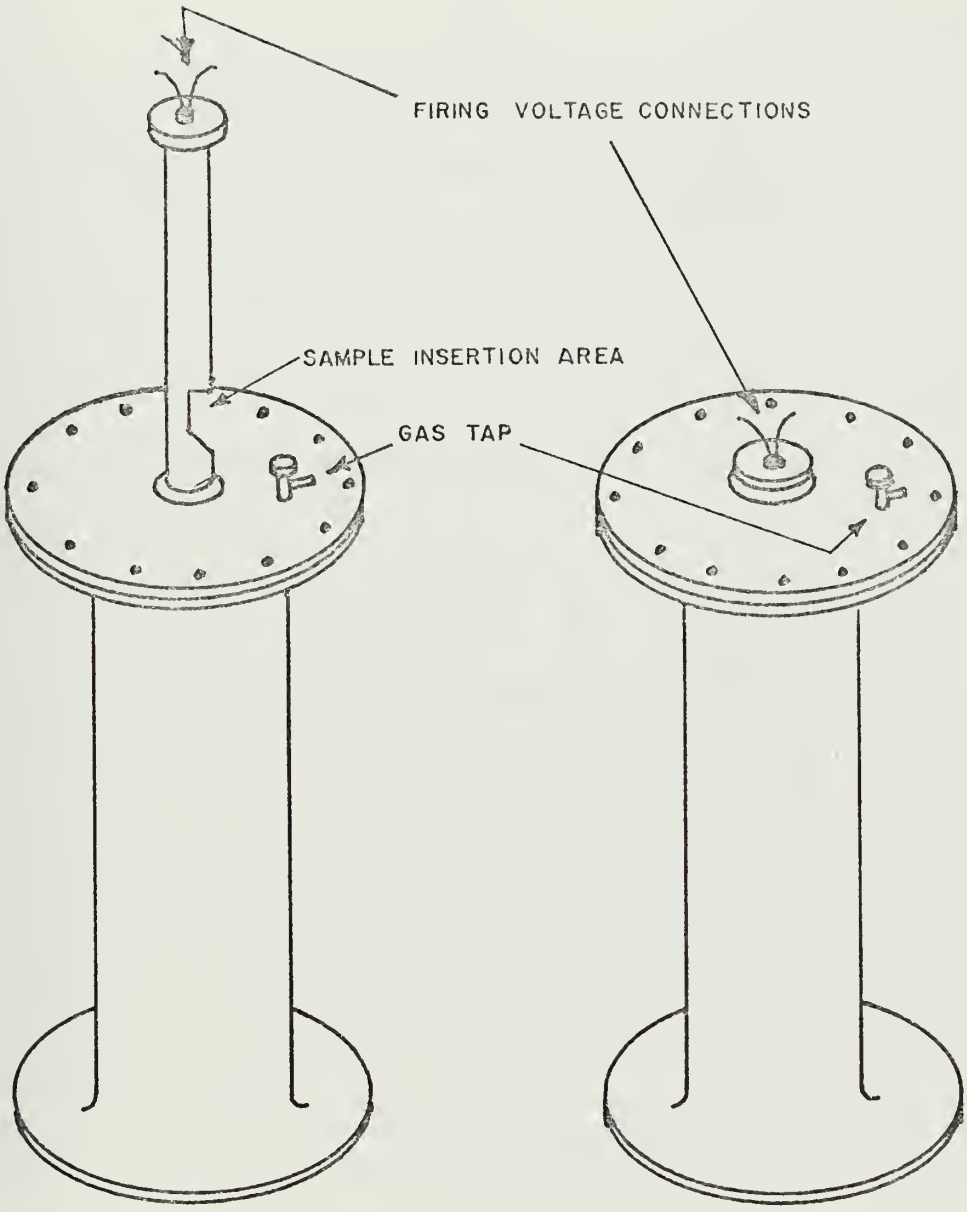


FIGURE 4: LOADING AND FIRING POSITIONS

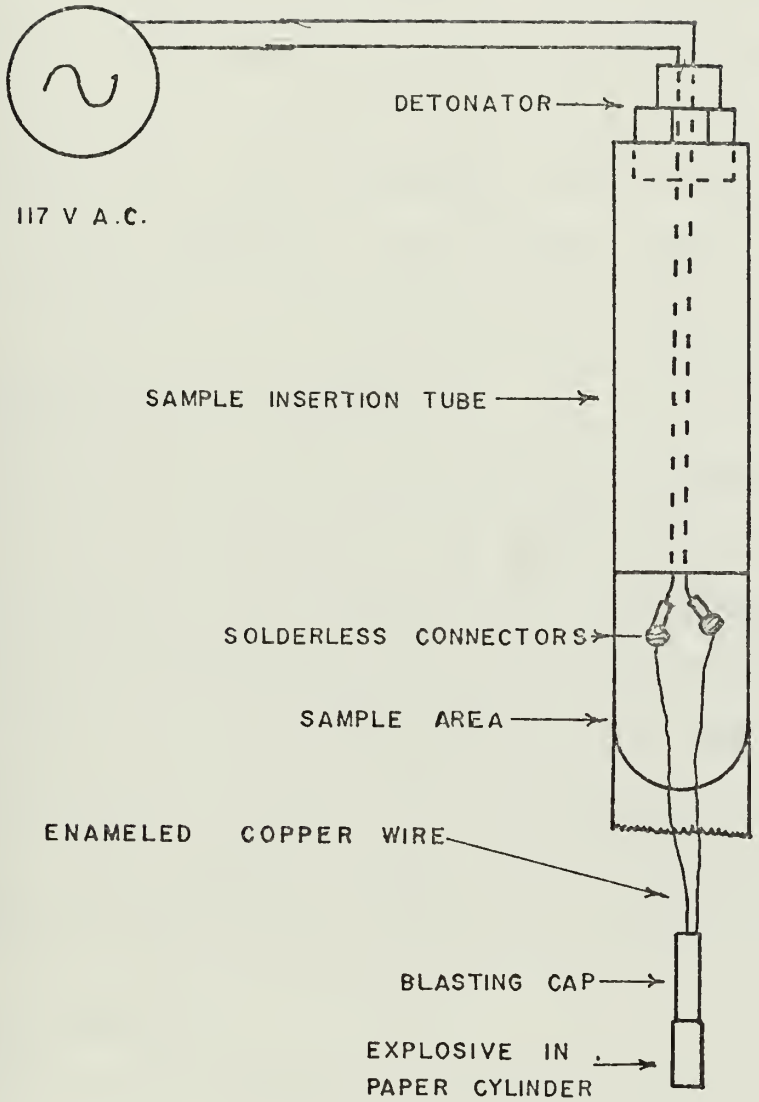


FIGURE 5: DETAIL OF FIRING ASSEMBLY

the base of the blasting cap. A small piece of insulating tape was placed between the solderless connectors, and another between the short blasting cap leads. The wires, cap, and explosive were placed in the sample area, and the insertion tube pushed down to the detonate position. The retaining ring was tightened and the A. C. line cord attached.

After firing, the retaining ring was removed, the insertion tube pulled up, and another sample loaded. Any number of samples could have been detonated in this manner.

B. PREPARATION OF EXPLOSIVE

The desired mass of explosive was weighed on an analytical balance and inserted into a paper cylinder of the same diameter as the blasting cap. The explosive was tamped solid, and the height of the explosive in the cylinder was measured. This measurement, along with the diameter and mass, gave an acceptable approximation of the packing density of the explosive. The loaded cylinders were stored in a dessicator to prevent contamination by laboratory atmospheres.

C. GAS SAMPLING

After each detonation, the chamber was allowed sufficient time to permit gas mixing and the establishment of thermal equilibrium. The needle valve was opened, and the sampling assembly was flushed momentarily by opening the flushing valve (FIG. 6). After closing the flushing valve, a blood sampling needle was inserted into the rubber septum, and an

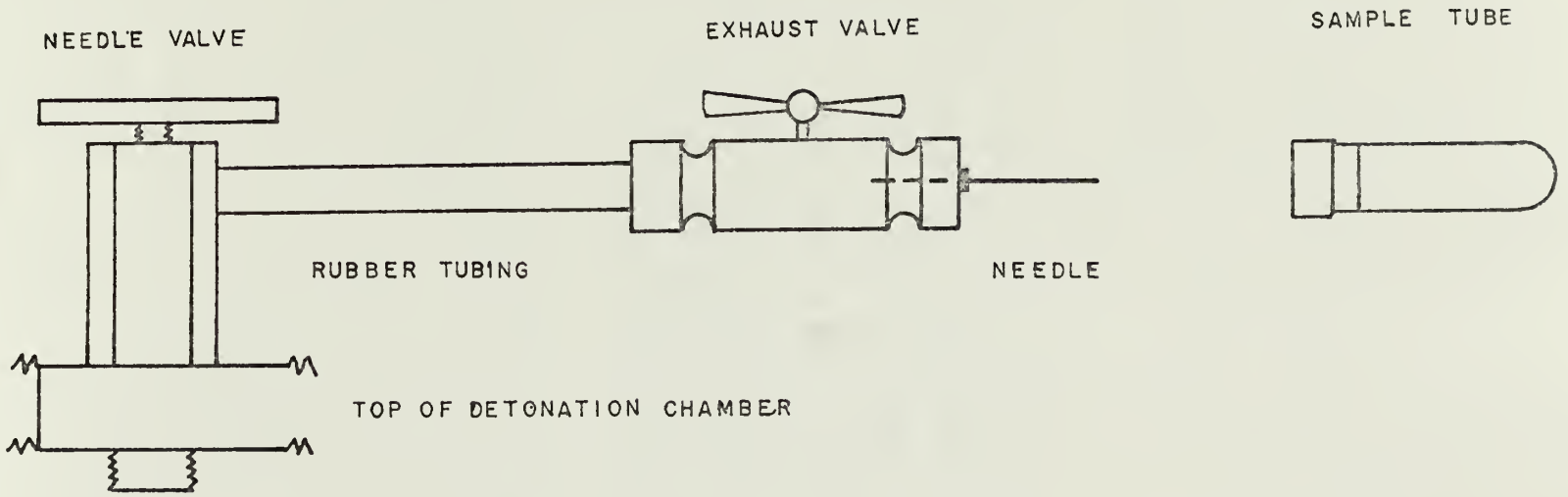


FIGURE 6: GAS SAMPLING ASSEMBLY

evacuated vial was punctured by the other end of the needle. This method permitted obtaining a pure gas sample rapidly, and with a minimum loss of pressure in the chamber. Three samples were usually taken from each detonation. Prior to the next detonation, the needle valve and the flushing valve were tightly closed. The samples were labeled and preserved for analysis.

D. GAS ANALYSIS

The gases resulting from each detonation were analyzed using the Fisher/Hamilton Gas Partitioner, catalog number 11-127V2, and the Varian Recorder, model G-14. The chart paper, Varian 45-A was found to be sufficiently uniform to allow weighing as a method of integration. The chart paper was run at high speed to produce larger areas of the peaks, thus improving the significant figures of the integrated result.

The gas partitioner was modified to produce a three column partitioner instead of a two column as originally designed. A third column was needed to serve as a freezing trap to delay the NO_2 and NH_3 if present in the sample. These gases were not distinguishable in the massive nitrogen peak, as the eluting time of the gases were similar. The boiling point of NO_2 is 21° C, and the boiling point of NH_3 is -33.35° C. The sample loop (FIG. 7)served as the freezing trap using a dry ice-acetone slurry with a temperature of -76° C.

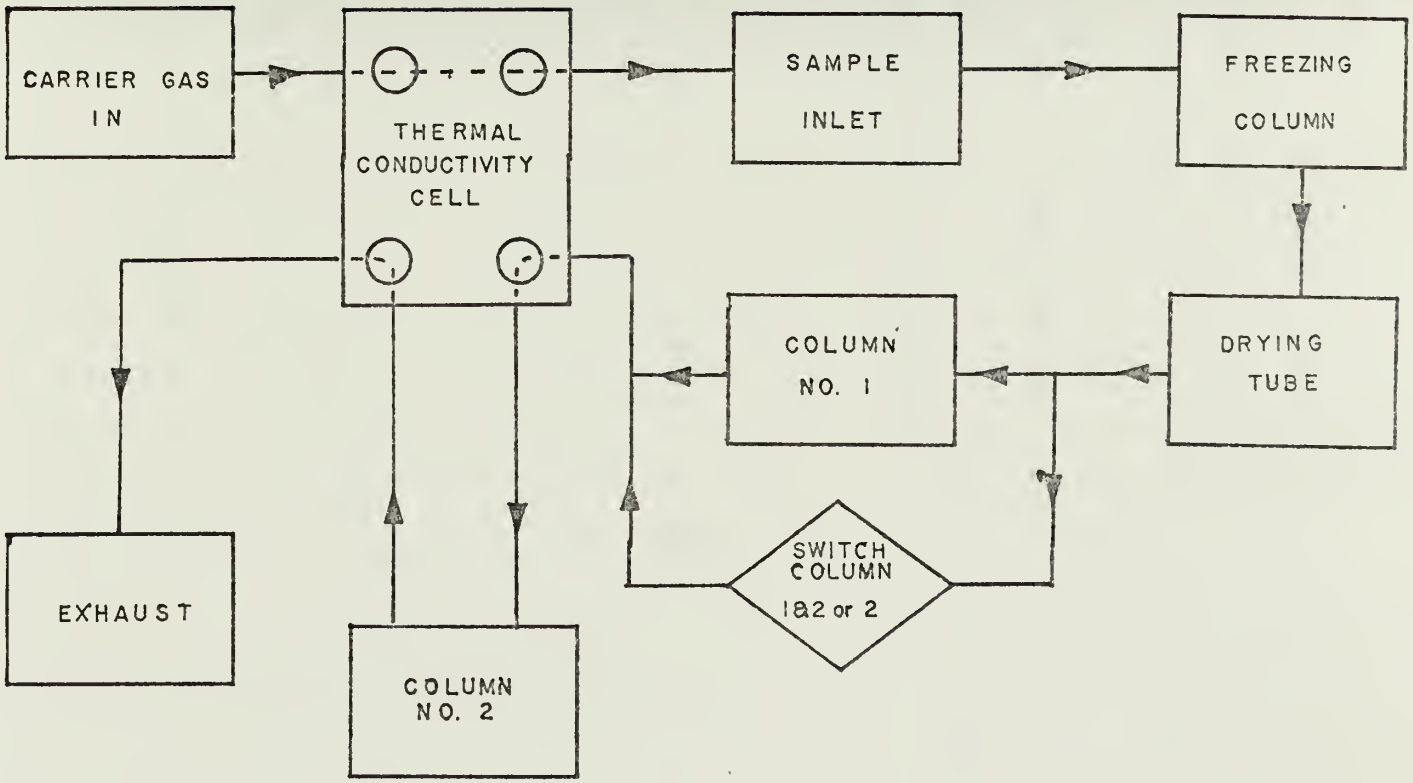


FIGURE 7: MODIFIED GAS PARTITIONER

The boiling points of all other gases in the analysis were sufficiently low to pass through the freezing trap unhindered. After the low boiling point gases had been recorded, the dry ice-acetone slurry was replaced with boiling water, and the frozen components were vaporized and recorded.

No other modifications were made to the published instructions. Nitrogen was used as the carrier gas for hydrogen analysis, and the one mililiter samples were inserted by the syringe method.

V. PRESENTATION OF DATA

A. FIRST FIRING SEQUENCE

The first sequence of explosives detonated was five one gram charges of C-4. This sequence was fired for a full check of all systems and was not intended to produce data.

B. SECOND FIRING SEQUENCE

The second sequence consisted of ten one gram detonations of C-4. The gases were analyzed for CO_2, O_2, CO, and Nitrogen compounds, as the separation by freezing was not devised at this point.

This detonation sequence was performed in ambient air, as would be the conditions in the underground test sites of the AEC. The results indicate the sampling technique was faulty, as the points on the graph vary greatly from any predictable pattern. It was felt that there should be more time allowed for mixing within the detonation chamber before sampling, and the volume flushed should be increased. Other than the lack of a good pattern, the system worked very well.

C. THIRD FIRING SEQUENCE

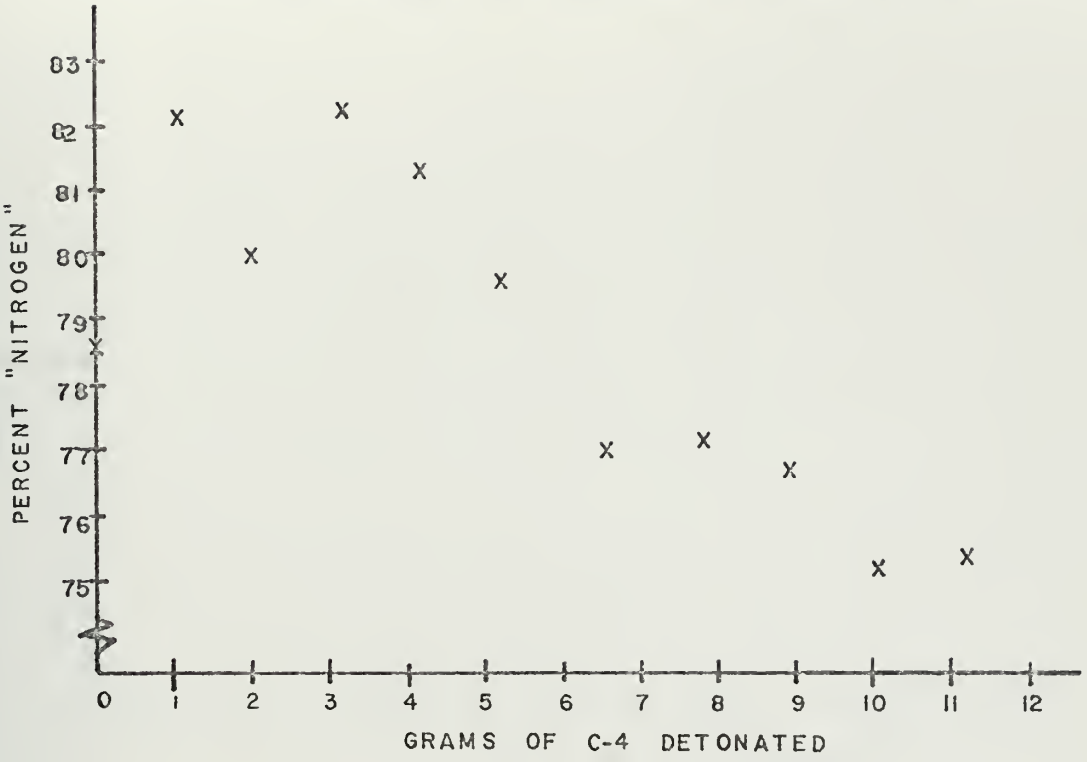
The third sequence was ten two gram detonations of TNT. The full analysis system was utilized, and the sampling technique was improved.

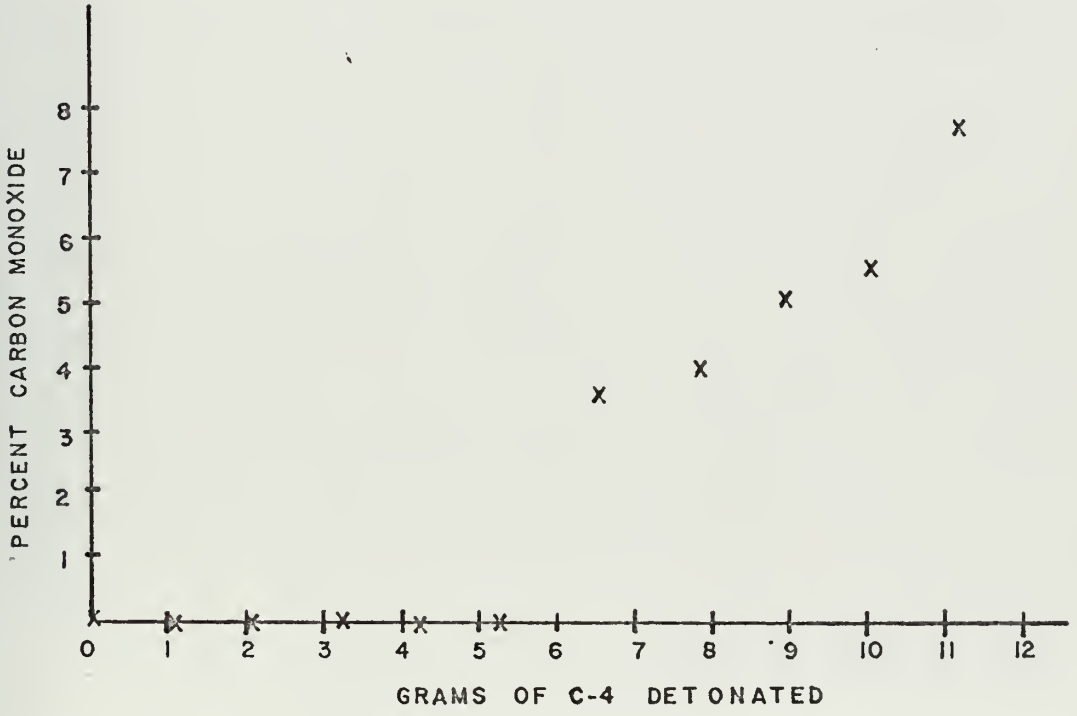
TABLE 1

EXPLOSIVE MASS AND SAMPLE ANALYSIS FOR FIRING SEQUENCE TWO

DETONATION NUMBER	MASS (g.)	COMPOSITE MASS (g.)	% O_2	%CO_2	%N_2	%CO
0	0.0	0.0	21.3	0.0	78.7	0.0
1	1.022	1.022	14.8	3.2	82.1	0.0
2	0.899	1.921	16.2	6.4	79.9	0.0
3	1.420	3.341	7.7	10.1	82.3	0.0
4	0.999	4.340	13.6	5.0	81.3	0.0
5	0.938	5.278	14.8	5.8	79.4	0.0
6	1.295	6.573	4.5	14.9	76.9	3.7
7	1.208	7.781	4.2	14.7	77.2	4.0
8	0.993	8.774	5.0	14.0	76.7	5.0
9	1.270	10.044	4.6	14.7	75.2	5.5
10	1.122	11.166	3.5	13.4	75.4	7.7

GRAPHS OF SECOND SEQUENCE





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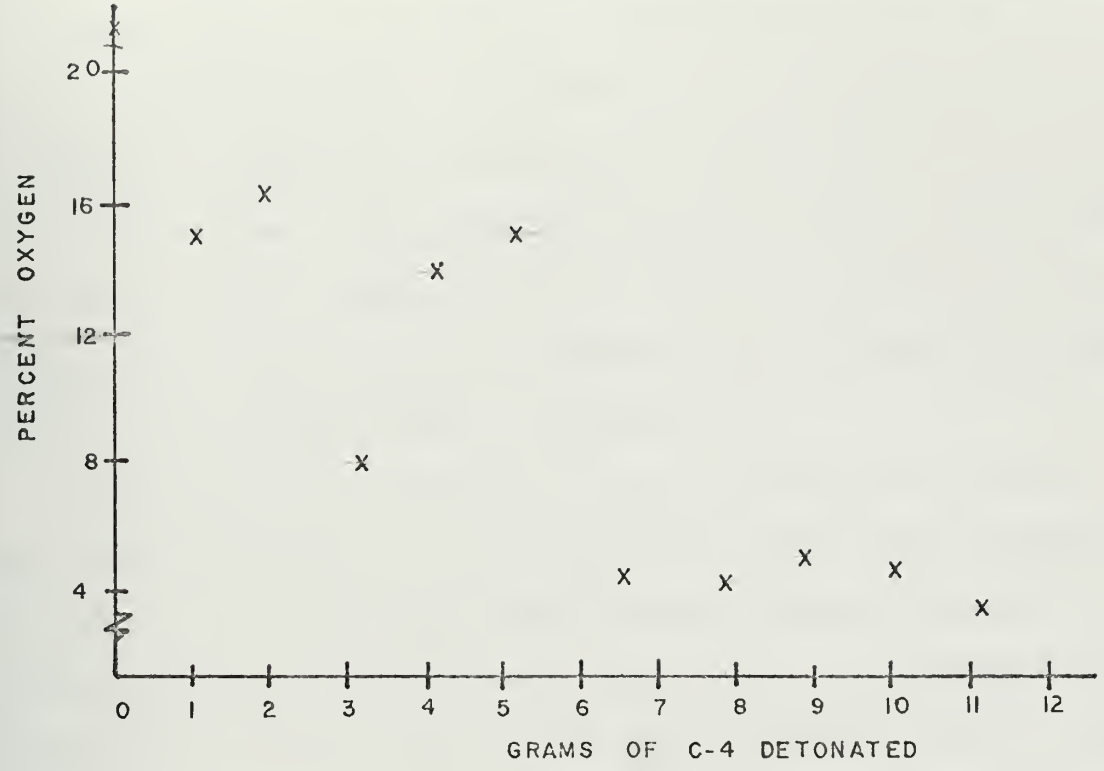
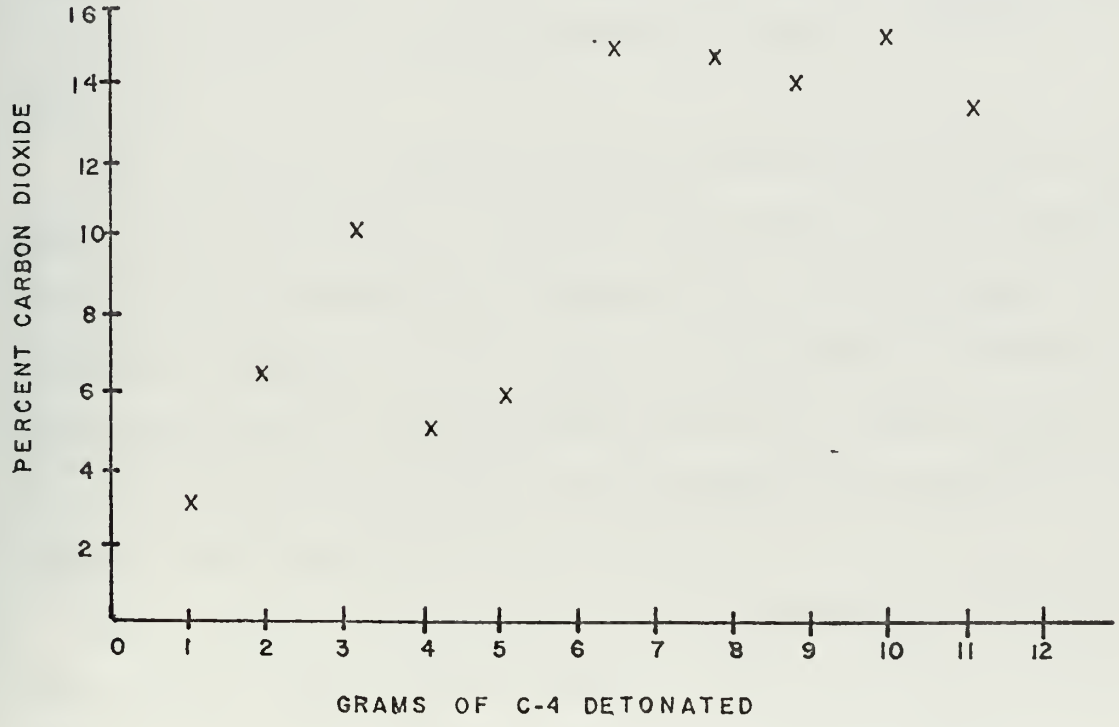




The packing density of the TNT was calculated to be 0.976, and the table in Cook, 1958, for the theoretical products of detonation was entered at the value of 0.95 for TNT. The value of the expected number of moles of each gas was converted to grams of gas per number of grams of explosive detonated. The value was corrected for the calculated pressure in the chamber, and the temperature.

The percentage of each gas was converted to grams of gas and corrected for the temperature and calculated pressure. A further correction was made for the gaseous products of the blasting cap used in each detonation (see APPENDIX E). This value is designated the Calculated Mass, and the value obtained by the theoretical products of detonation is labeled the Theoretical Mass in the graphs of sequence three and table two.

The analysis of sequence three was performed seven days after detonation, and the samples were kept in the dark in a helium flushed container. Traces of NO_2 and NH_3 were observed in samples 18, 19, and 20, but were too minute to lend themselves to quantitative analysis. Using nitrogen as a carrier gas, an analysis for hydrogen was attempted. The results were negative.

The graphs of the weight of gas produced as a function of the weight of TNT detonated gave a good indication of the behavior of the explosive. The theoretical value of the grams of oxygen should not have changed as the oxygen does

not enter into the chemistry of pure detonation. The rapid depletion of the oxygen indicated that combustion had also occurred to some extent in the chamber. This was further evidenced by the failure of the carbon monoxide level to rise as it should have, and the greater amount of carbon dioxide than expected. The carbon in the TNT was converted primarily to carbon dioxide instead of the expected carbon monoxide.

To determine equilibrium effects, the samples analyzed at one week were compared with samples analyzed one day after detonation, and two weeks after detonation. Due to the lack of quantitative sensitivity in the nature of tenths of a percent, the results could not be confirmed. There were no major changes in the concentration of any gas during a period of two weeks.

Water was not analyzed due to the nature of the gas partitioner in that it incorporated a water absorption column to protect the sensors. Samples 18, 19, and 20 were dried by a dessicant and the absorption column was bypassed to determine ammonia, due to ammonia's solubility in the absorbed water. This bypass was considered too dangerous to the machine for the analysis of water.

TABLE 2

EXPLOSIVE MASS AND SAMPLE ANALYSIS FOR FIRING SEQUENCE THREE

DETONATION NUMBER	MASS (g)	COMPOSITE MASS (g)	$\%O_2$	$\%CO_2$	$\% N_2$	% CO
0	0.0	0.0	21.3	0.0	78.7	0.0
11	1.650	1.650	13.3	5.9	80.72	0.0
12	1.673	3.323	11.5	7.5	81.0	0.0
13	1.900	5.223	9.6	9.2	81.2	0.0
14	1.832	7.055	8.3	9.5	79.7	2.4
15	1.912	8.967	7.3	10.0	79.2	3.4
16	1.949	10.916	6.4	11.6	77.5	4.5
17	2.158	13.074	5.6	13.1	76.1	5.2
18	2.128	15.202	4.2	13.6	76.1	6.1
19	1.913	17.115	4.0	13.9	75.2	6.9
20	2.143	19.258	3.9	14.8	73.7	7.6

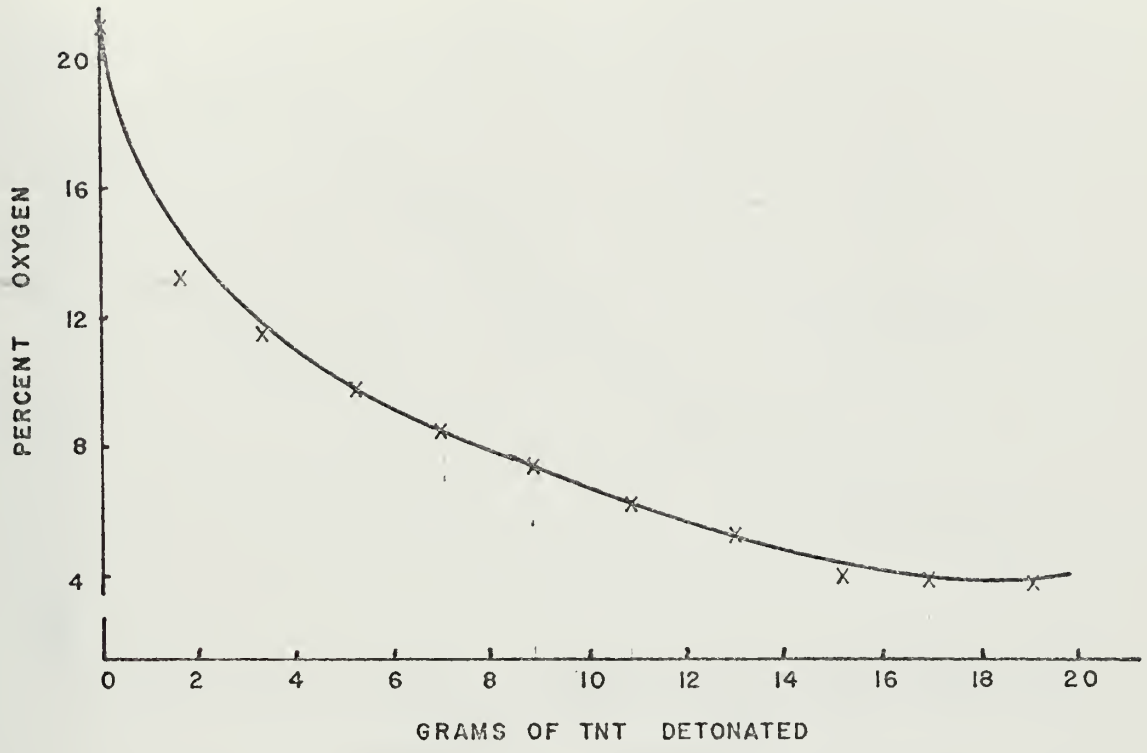
TABLE 2 (cont.)

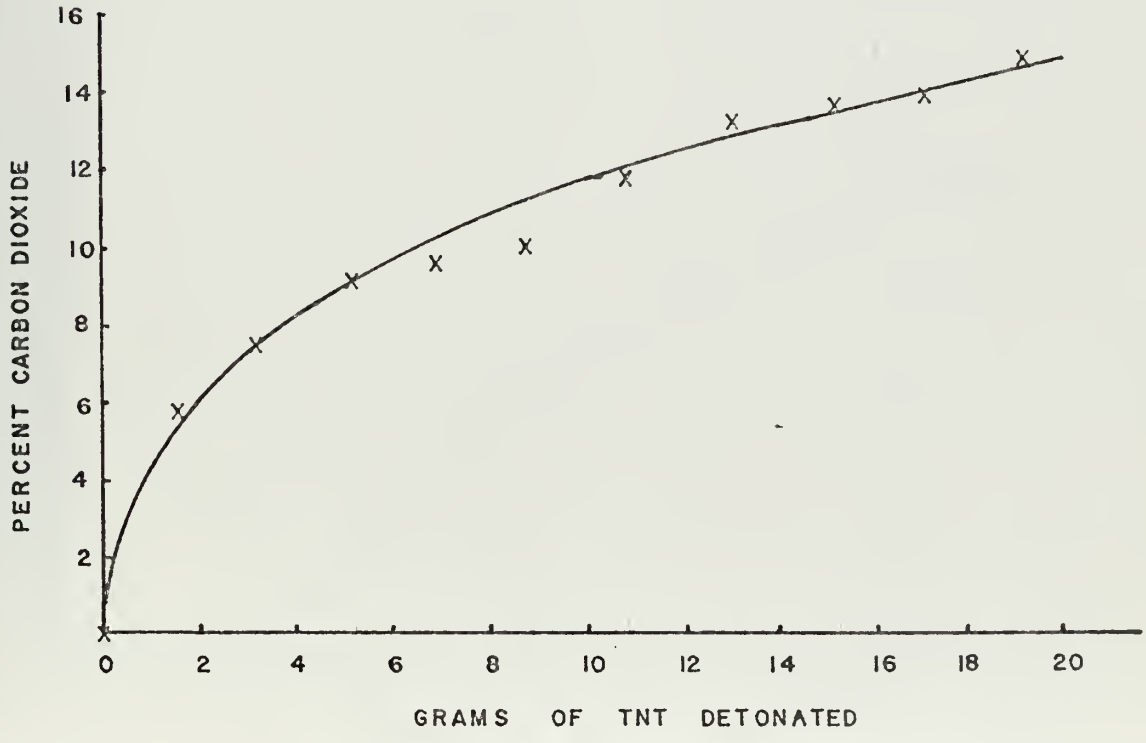
DETONATION NUMBER	CALCULATED MASS O_2 (g.)	THEORETICAL MASS O_2 (g.)	CALCULATED MASS CO_2 (g.)	THEORETICAL MASS CO_2 (g.)
0	5.547	5.547	0.0	0.0
11	3.765	5.547	2.297	0.378
12	3.504	5.547	3.142	0.760
13	3.163	5.547	4.168	1.195
14	2.933	5.547	4.616	1.614
15	2.762	5.547	5.203	2.052
16	2.500	5.547	6.231	2.498
17	2.418	5.547	7.778	2.991
18	1.929	5.547	8.591	3.478
19	1.938	5.547	9.258	3.916
20	1.998	5.547	10.425	4.406

TABLE 2 (cont.)

DETONATION NUMBER	CALCULATED MASS N_2 (g.)	THEORETICAL MASS N_2 (g.)	CALCULATED MASS CO (g.)	THEORETICAL MASS CO (g.)
0	17.934	17.934	0.0	0.0
11	19.995	18.174	0.0	0.462
12	21.596	18.418	0.0	0.930
13	23.407	18.694	0.0	1.462
14	24.646	18.961	0.742	1.975
15	26.224	19.240	1.126	2.511
16	26.491	19.523	1.538	3.056
17	28.752	19.838	1.965	3.661
18	30.591	20.147	2.452	4.257
19	31.874	20.426	2.925	4.792
20	33.035	20.738	3.407	5.392

GRAPHS OF THIRD SEQUENCE





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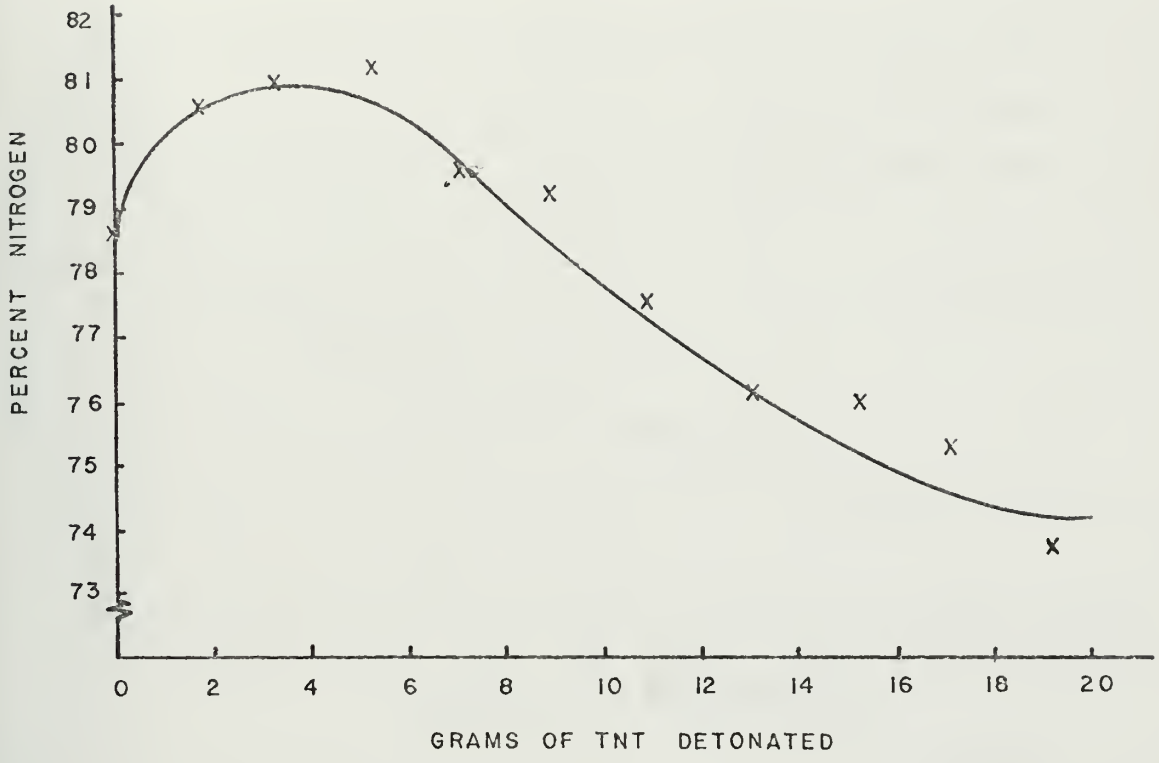

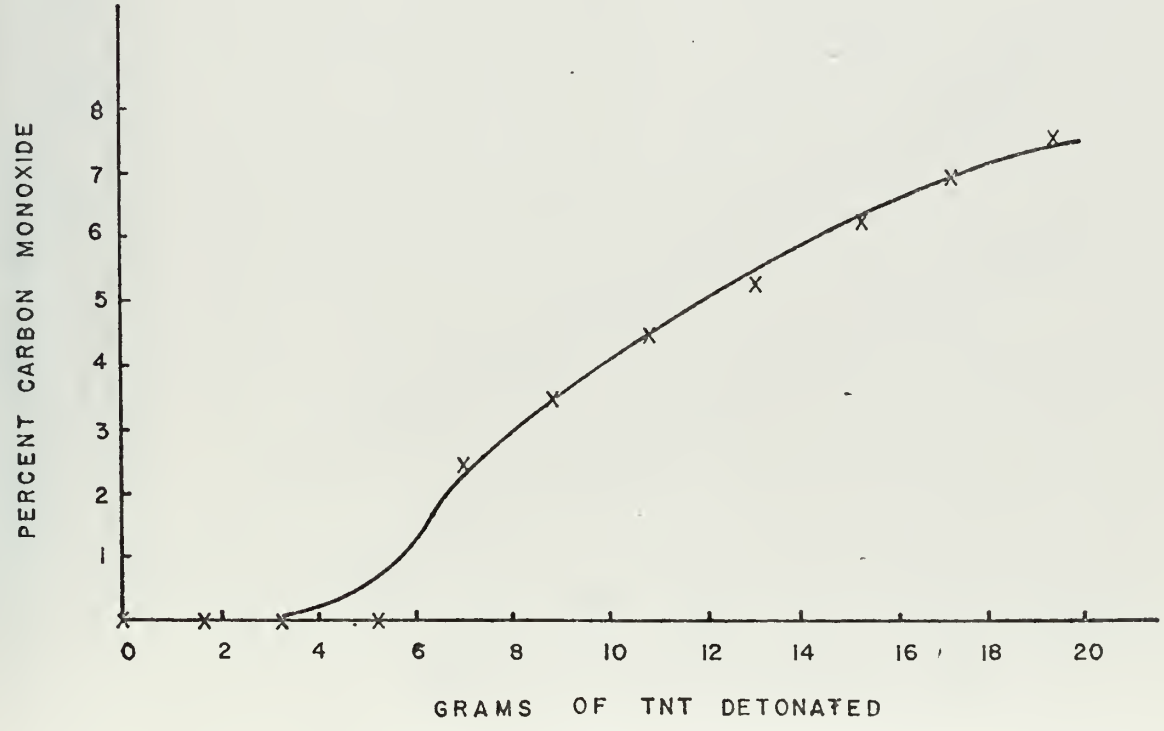

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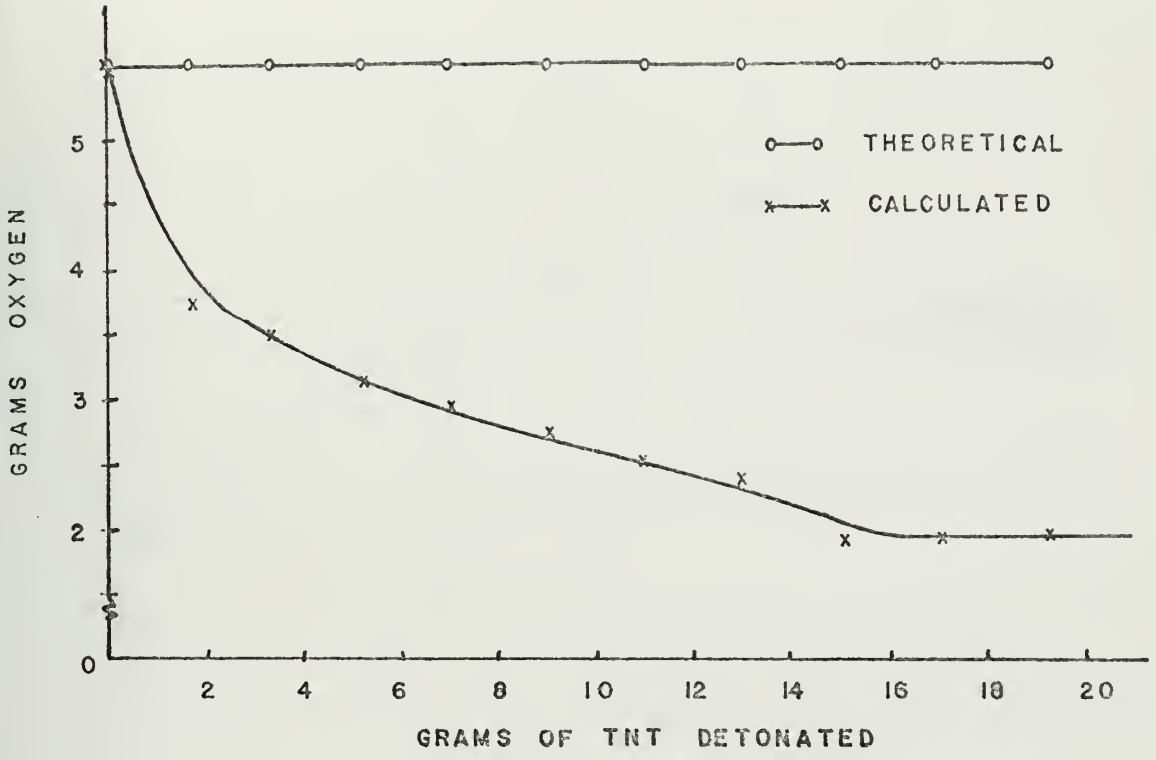

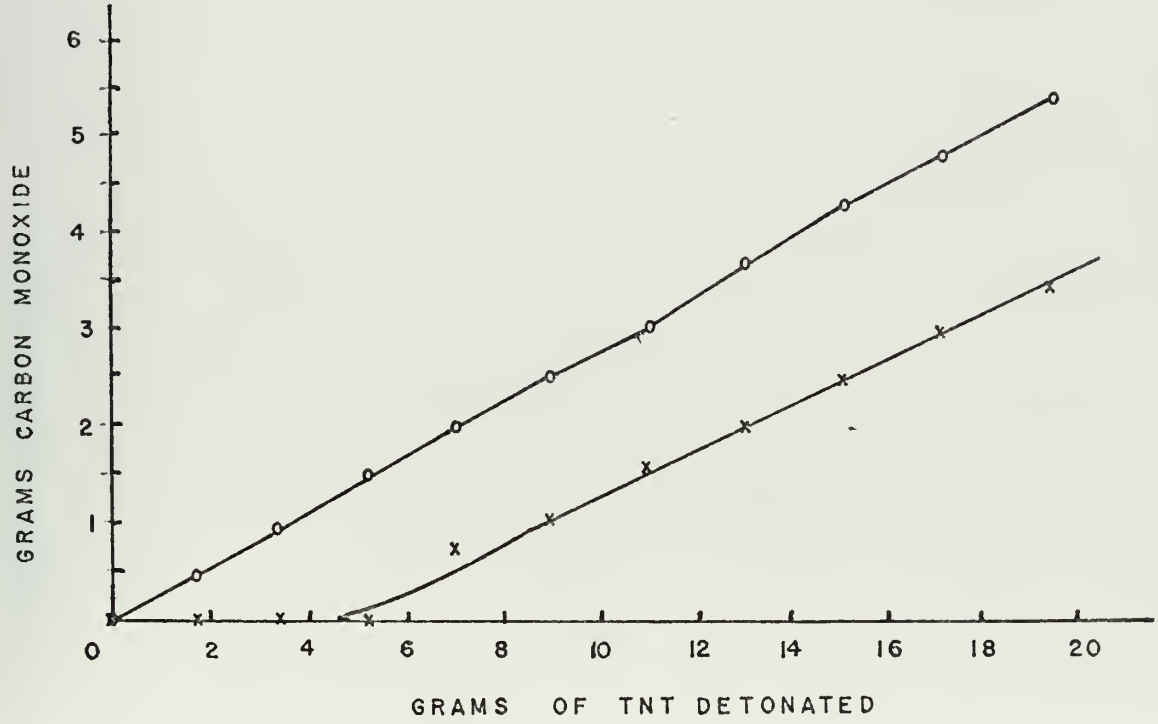

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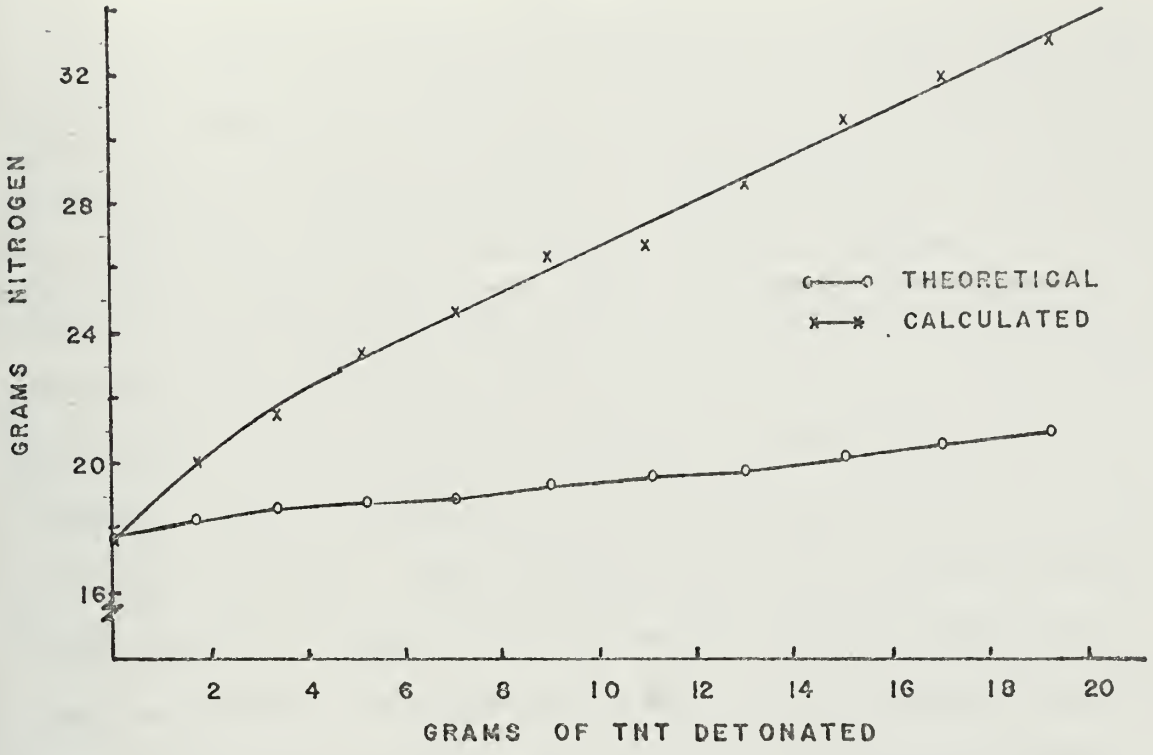

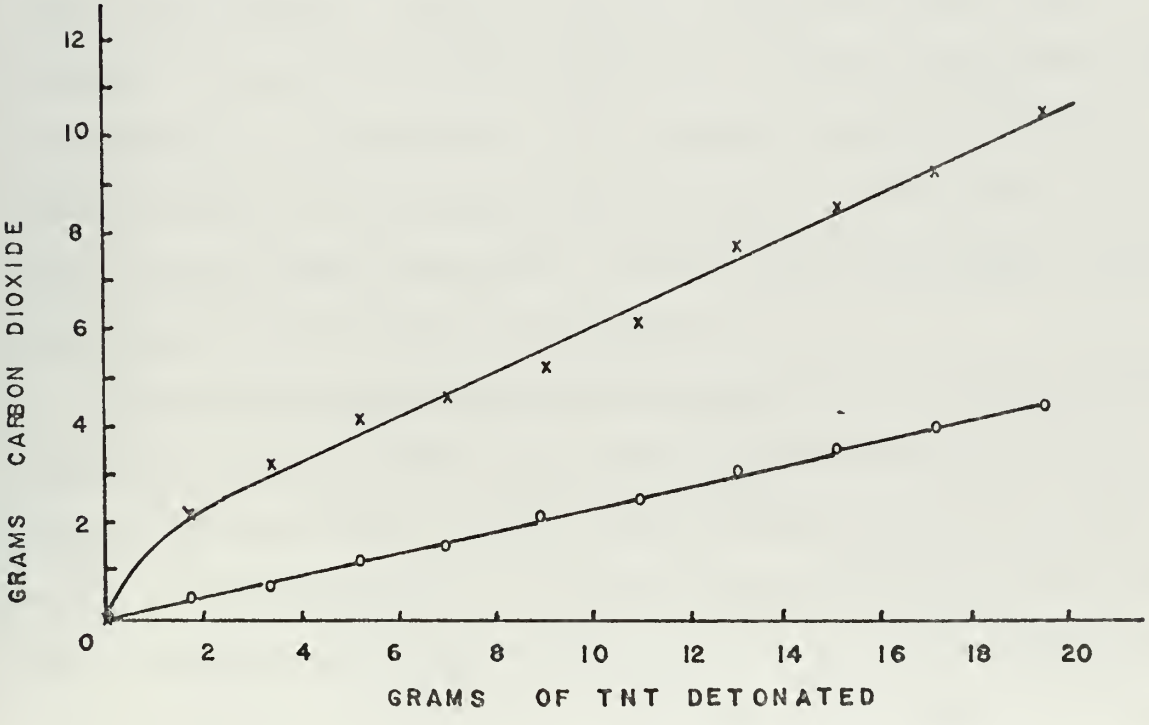

VI. APPLICATION

From the basic research conducted on a scaled down detonation chamber, the feasibility of underground detonation of explosives has been explored. The desired result would be the implementation of the research into a program which would utilize the AEC owned test sites as an explosive chamber for the disposal of up to several thousand tons of conventional explosives. It is envisioned that the explosives could be lowered into the underground chamber along with a detonation initiating device. The loading port could then be plugged with a concrete wedge, and detonation accomplished with a timer mechanism. Complete detonation of the entire explosive train would be assured by the factors of proximity and confined shock waves. Later, the site could be tapped and vented when meteorological conditions are most favorable for the disposal of pollutants. An unstable weather condition would dispose of the gases effectively, as soil acts as a sink for the carbon monoxide, and the upwelling would spread the gases to a nontoxic concentration.

Trinitrotolulene was studied extensively in this research since many of the older explosives consist mainly of TNT. On an expanded scale, an AEC site one-half mile in diameter would enable detonations of 30,000 tons per firing, and the gas and pressure increase would be similar to the detonation chamber model. Of the most toxic gases, the only one present

in quantity was carbon monoxide in the research. On a larger scale, it would be unreasonable not to expect toxic quantities of other gases, especially the oxides of nitrogen. Analysis prior to venting would establish their presence and quantity. If necessary, the gases could be scrubbed either chemically or mechanically prior to release to the atmosphere.

The solid particulant matter remaining after detonation consisted mainly of carbon. This would present no problem, as it would settle to the bottom of the site. The metals of the casing, fuse assembly, and other areas could be mined and reclaimed if it was deemed economically profitable.

APPENDIX A

CALCULATION OF THE VOLUME OF THE DETONATION CHAMBER

The detonation chamber is a right circular cylinder.

Interior dimensions are:

Height	36.0 inches
Radius	3.25 inches

Volume = $\pi r^2 h$

= $3.14 \cdot 3.25^2, 36.0$

= $1193.98\ in^3$

$1193.98\ in^3 \times 16.38\ cm^3/in^3 \times 1\ liter/1000\ cm^3$

= 19.57 liters

APPENDIX B

PRESENTATION OF THE SEWELL-SINCLAIR EQUATION AND SOLUTION FOR ONE KILOGRAM OF TNT

The equation is:

$$\Delta V_{cd} = \left[(G-\frac{S}{G})\right] \Delta V_d + \left[1- \left(\frac{G - S}{G} \right)\right] \Delta V_c$$

where

ΔV_{cd} = The change in volume when the explosive is partly burned and partly detonated.

ΔV_d = The change in volume when the explosive is detonated.

ΔV_c = The change in volume when the explosive is burned.

S = The stoichiometric amount of the explosive in grams.[1]

G = The grams of explosive.

When TNT is burned [Little, 1943], the equation is:

$$C_7H_5N_3O_6 + 5.25\ O_2 = 7CO_2 + 2.5\ H_2O + 1.5\ N_2$$

$$\Delta V_c = (7 + 2.5 + 1.5) - 5.25 = 5.75 \text{ moles gas/mole expl.}$$

When TNT detonates [Little, 1943], the equation is:

$$C_7H_5N_3O_6 = 6CO + 2.5H_2 + 1.5N_2 + C_{solid}$$

$$\Delta V_d = (6 + 2.5 + 1.5) = 10 \text{ moles gas/mole expl.}$$

The detonation chamber volume was 19.566 liters. Since air is 21% oxygen, the chamber contained

$$19.57 \text{ liters} \times 0.21/22.4 \text{ liter/mole} = 0.1834 \text{ moles } O_2.$$

---

[1]The stoichiometric amount is defined as the grams of explosive that would burn in the amount of oxygen present in the container.

If one mole of TNT requires 5.25 moles of oxygen, then

0.1834 moles of oxygen will combust

$$\frac{0.1834}{5.25} \times 227 = 7.92 \text{ grams TNT.}$$

This is the stoichiometric amount "S".

The Sewell-Sinclair equation can now be solved for 1000g TNT.

$$\Delta V_{cd} = (1000 - \frac{7.92}{1000}) \times 10 + \left[1-(\frac{1000 - 7.92}{1000})\right] \times 5.75$$

$$= 9999.9665 \text{ moles gas/mole TNT}$$

$$9999.9665 \frac{\text{moles gas}}{\text{mole TNT}} \times \frac{1 \text{ mole}}{227 \text{ g}} \times \frac{22.4 \text{ liters}}{\text{mole}} = 986.78$$

liters.

Pressure in detonation chamber = $1 + \frac{986.78}{19.57} = 51.43$

atmospheres.

APPENDIX C

CALCULATION OF ΔV_{cd} FOR 20 GRAMS TNT

$$\Delta V_{cd} = \left(G - \frac{S}{G}\right) \Delta V_d + \left[1 - \left(\frac{G - S}{G}\right)\right] \Delta V_c$$

$$= \left(20 - \frac{7.92}{20}\right) 10 + \left[1 - \left(\frac{20 - 7.92}{20}\right)\right] 5.75$$

$$= 19.57 \text{ liters}$$

Pressure in the detonation chamber = $1 \frac{19.57}{19.57} = 2.000$ atmospheres.

APPENDIX D

CORRECTIONS TO THEORETICAL PRESSURE CALCULATIONS

Volume of gas produced by blasting cap (APPENDIX E); 50 ml.

Exhaust bleed; estimated 150 ml.

Sample volume; four samples consisting of five ml. each.

Volume lost in sample insertion area; 50 ml.

Total gas volume correction per shot;

250 ml. - 100 ml. - 20 ml. - 50 ml. = 80 ml.

APPENDIX E

ANALYSIS OF BLASTING CAP AND CORRECTIONS TO SAMPLE ANALYSIS

A single blasting cap of the type used in all detonations in the detonation chamber was detonated in an evacuated chamber. The volume of gas produced, corrected for temperature and pressure was 250 ml. The analysis indicated the following masses of gases should be subtracted from the sample analysis.

Nitrogen	0.31 g.
Oxygen	0.0
Carbon dioxide	0.0
Carbon monoxide	0.0

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ABSTRACT
A miniature detonation chamber has been designed and manufactured to allow loading, detonation, reloading, and gas sampling without appreciable loss of products or pressure. The actual products of detonation are compared with the theoretical products. From this comparison, a study is made of the effects on the environment from sequential, confined detonation of conventional explosives in an Atomic Energy Commission test site.

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Disposal of conventional weapons by confined detonation.